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A review of the meanings and the implications of the Industry 4.0 concept

A.C. Pereira*, F. Romero

Department of Production and Systems, University of Minho, 4800-058 Guimarães, Portugal

Abstract

The global industrial landscape has changed deeply in the last few years due to successive technological developments and innovations in manufacturing processes. The Industry 4.0 concept has emerged and the academic literature has paid an increased attention to this topic, which remains non-consensual or ill defined. In this research, a literature review is made to understand this concept in its technological dimension, and to comprehend its impacts. This new industrial paradigm brings together the digital and physical worlds through the Cyber-Physical Systems enhanced by Internet of Things and it is expected that this novel has consequences on industry, markets and economy, improving production processes and increasing productivity, affecting the whole product lifecycle, creating new business models, changing the work environment and restructuring the labor market. Therefore, this paper focuses on Industry 4.0 concept and contributes for its clarification and further understanding about the importance and implications of this complex technological system.

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1. Introduction

In the last years, with the growing advancements in manufacturing processes and technology, many new global concepts have emerged. The term “Industry 4.0” has become an increasingly important topic in the last few years.

* Corresponding author. Tel.: +351 253 510 344.

E-mail address: id6721@alunos.uminho.pt

This concept appeared firstly in an article published in November 2011 by the German government that resulted from an initiative regarding high-tech strategy for 2020 [1].

The global industrial landscape has changed deeply in the last years and is a result of successive technological developments and innovations. Industry 4.0 can be tentatively compared with three industrial revolutions that occurred in the last centuries and that represent the main disruptive changes in manufacturing that have resulted from several technological advances [2].

The First Industrial Revolution took hold in England in the middle of the 18th century and was potentiated by the invention of the steam engine. During the second half of 19th century, the Second Industrial Revolution came up in Europe and USA. This revolution was characterized by mass production and the replacement of steam by chemical and electrical energy. In order to meet the growing demand, several technologies in industry and mechanization have been developed, such as the assembly line with automatic operations, allowing the increasing of productivity. The invention of the Integrated Circuit (microchip) was the technological advancement that has triggered the Third Industrial Revolution. The use of electronics and Information Technology in order to achieve further automation in production is the key feature of this revolution that emerged in the last years of 20th century in many industrialized countries around the world [3], [4].

The increasing productivity is the core of every industrial revolution. The first three industrial revolutions had a strong impact in industrial processes, allowing productivity and efficiency increase through the use of disruptive technological developments, such as steam engine, electricity or digital technology [5]. Industry 4.0, which may eventually represent a fourth industrial revolution, is a complex technological system that has been widely discussed and researched, having a great influence in the industrial sector, since it introduces relevant advancements that are related with smart and future factories. This emerging Industry 4.0 concept is an umbrella term for a new industrial paradigm that embraces a set of future industrial developments regarding Cyber-Physical Systems (CPS), Internet of Things (IoT), Internet of Services (IoS), Robotics, Big Data, Cloud Manufacturing and Augmented Reality. The adoption of these technologies is central to the development of more intelligent manufacturing processes, which includes devices, machines, production modules and products that are able to independently exchange information, trigger actions and control each other, enabling an intelligent manufacturing environment [6].

This new approach will bring together the digital and physical worlds through the CPS technology, embracing a set of future industrial developments that will allow the improvement of productivity and efficiency among the companies that are adopting this new manufacturing paradigm [1]. Industry 4.0 holds a huge potential and it will provide a set of economic and social opportunities through the paradigm shift regarding to work organization, business models and production technology [7].

The influence of Industry 4.0 is being researched by academics and companies in recent years, which has resulted in an increasing number of publications about this topic. However, this concept that intends to highlight the new industrial environment and the involved technological advancements is not always consensual, as well as its potential consequences in industry and manufacturing, which are not yet clearly defined. The purpose of this paper was the comprehensive understanding about the Industry 4.0 concept, as well as a research about its importance, regarding the impacts, challenges and opportunities for the organizations that adopt this novel approach.

This paper is structured in seven sections. After this introduction about the Industry 4.0 phenomenon, section 2 explains the research methodology and section 3 provides a comprehensive definition about this concept, presenting several points of view about Industry 4.0 visions and concepts. The key Industry 4.0 technology enablers are described in section 4, while the section 5 provides an analysis about the impacts and influence of this new industrial paradigm. Lastly, section 6 draws the main conclusions and findings about Industry 4.0 concept and implications.

2. Research Methodology

In order to understand the importance of Industry 4.0 as a complex technological system, and in order to attempt a consolidation of this nonconsensual concept, a comprehensive literature review was carried out using the main scientific literature databases, journal articles, conference papers, books and other documentation, as the source of the utilized secondary data. Furthermore, the literature review was conducted considering the following electronic databases: ISI Web of Knowledge, Elsevier (Science Direct), Scopus, Emerald Insight and Springer, over the 2000-2017 timeframe period. The objectives of this investigation consisted in: (1) the identification of the main articles and

studies about this concept and the comparison between the different theories and points of view, (2) the statement of the main evolutions and technological developments regarding Industry 4.0, as well as the most significant innovations and trends, and the challenges that will result from these advancements and, lastly, (3) the analysis about the influence and potential industrial, economic and social consequences of this new industrial paradigm.

3. Industry 4.0 Concept

The term “Industry 4.0” is often referred to as the fourth industrial revolution and embraces a set of technological advances that are having a high impact in the current industrial landscape. In this section, the background of Industry 4.0 phenomenon is analyzed, as well as the future manufacturing vision enabled by this new manufacturing paradigm. Additionally, the key features about this nonconsensual concept are presented in order to better understand the main meanings of Industry 4.0.

3.1. Background of Industry 4.0

Industry 4.0 is a concept that emerged in the last years due to technological advancements and disruptive developments in the global industrial sector. The term “Industry 4.0” appeared firstly in an article published in November 2011 by the German government that resulted from an initiative regarding high-tech strategy for 2020 [1]. The concept draws on earlier concepts and perspectives that evolved over the years [8], [9].

The industrial landscape has changed drastically in the last few years as a result of successive innovations and disruptive developments, particularly in the field of digital technology and manufacturing. Industry 4.0 is being compared with the first three industrial revolutions that occurred in the last centuries [2]. The first industrial revolution improved productivity and efficiency through the use of steam power, the second allowed mass production through the use of electricity while the third industrial revolution was characterized by production automation using electronics and IT [4].

The emerging fourth industrial revolution, often referred as Industry 4.0, involves fast and disruptive changes that embrace digital manufacturing, network communication, computer and automation technologies, as well as many other relevant areas [1]. This new industrial paradigm embraces a set of technological developments, such as CPS, IoT, Robotics, Big Data, Cloud Manufacturing and Augmented Reality, that will influence both products and processes, allowing efficiency and productivity improvements among companies that will adopt such technologies [2]. Furthermore, Industry 4.0 will lead to deep changes in industry and manufacturing sectors, having strong impacts along the whole value chains and providing a set of new opportunities regarding business models, production technology, creation of new jobs and work organization.

3.2. Future Manufacturing Vision

The future of production as predicted by Industry 4.0 consists in pervasive integration, where every manufacturing elements autonomously exchange information, trigger actions and control themselves independently [6]. This manufacturing approach that intends to create smarter processes is characterized by small decentralized and digitalized production networks that act without human intervention and autonomously control their operations depending on their environment changes and requirements [10].

The Industry 4.0 concept can be seen as a fundamentally new approach that will bring together the digital and physical worlds. Researchers and companies hold different points of view about the Industry 4.0 concept and visions, but there is a consensus about the main aspects that address the future manufacturing vision [11]: (1) Smart Factory, (2) Smart Products, (3) Business Models and (4) Customers.

The term “smart” is becoming central within Industry 4.0 framework, though it is not easy to find an accurate definition. However, a possible definition of this concept that meets several authors’ vision can be associated with independent and autonomous devices that are able to communicate in real-time and cooperate in a smart environment with other smart devices, making decisions and performing actions that are based in the obtained information [12].

Industry 4.0 is a new manufacturing paradigm that is highly focused on the creation of smart products and processes, through the use of smart machines and the transformation of conventional manufacturing systems into smart factories.

Smart Factory is one of the key aspects that addresses this new industrial revolution, having resulted from several developments that consisted in integration, digitization and the use of flexible structures and smart solutions [13]. These manufacturing solutions allows the creation of an intelligent environment along the entire value chain, enabling the performance of flexible and adaptive processes [12]. A smart factory environment consists in a new integrative real-time intercommunication between every manufacturing resource (sensors, actuators, conveyors, machines, robots, etc.) [11], which increases the manufacturing efficiency and allows the meeting of highly complex market requirements [7].

Smart Products are integrated with the whole value chain as an active part of the systems, monitoring their own production stages through data storage, being able to request the required resources and control the production processes autonomously. Furthermore, smart products, as final products, should be self-aware about the parameters within they should be used, providing information about their status during their whole lifecycle [7]. Smart products can be described as CPS due to their capability of enabling the connection between physical and virtual worlds [14]. These products are characterized by several key features such as computation, data storage, communication and interaction with their environment, being able to identify themselves, storing data about their production process and providing information about further steps regarding production and maintenance. Furthermore, smart products have a high degree of autonomy, being able to perceive and interact autonomously with their physical environment over their lifecycle [2].

Business Models are being highly influenced by Industry 4.0, since this new manufacturing paradigm implies a new way of communication along supply chains. Business modelling is changing in the last few years due to new industrial and market requirements and new business models are emerging, allowing the creation of collaborative environments [15]. There are many opportunities for optimizing value creation processes and integration through the value chain, in order to achieve self-organization capability and real-time integration and communication [11].

Customers are a key factor in every business model and Industry 4.0 brings a set of advantages for them, improving communication along the value chain and enhancing the customer's experience. The high level of integration and the autonomous exchange of information will allow real-time requirements change. Additionally, smart products will provide relevant information to their users about their status and utilization parameters [11].

Briefly, smart factories are connected to a value chain in order to fulfil market requirements and consist in the integration between machines and materials through standardized interfaces. Smart materials and smart products are tracked along their whole lifecycle time, allowing a high degree of customization. Industry 4.0 is bringing the emergence of new business models that better meet customers' changing requirements, through the real-time communication capability along the whole supply chain [10].

3.3. Key Features of Industry 4.0

Industry 4.0 concept has become an increasingly important topic, being discussed and researched by academics and companies in recent years. However, despite the increasing interest about Industry 4.0 topic, it is still a non-consensual concept. There is no clear vision about this new manufacturing paradigm, regarding its implications and consequences. Furthermore, most companies are not aware about the challenges that will be faced when they adopt Industry 4.0 framework. However, it is believed that Industry 4.0 is still in a conceptual state and the misunderstanding about this topic starts with what involves Industry 4.0 and its meaning and vision. Unlike the past revolutions, this fourth industrial revolution is being predicted, which allows the companies to take actions to prepare this transformation, defining the most suitable manufacturing model and planning the target roadmaps in order to address this new industrial paradigm's challenges [16].

Oesterreich and Teuteberg [17] stated that, from the technical point of view, this new industrial paradigm can be described as the manufacturing environment's increased digitization and automation in addition to an increased communication enabled by the creation of a digital value chain [17]. According to Kagermann et al. [7], the main features of the Industry 4.0 concept are characterized by three dimensions of integration [7]: (1) horizontal integration through value networks, (2) vertical integration and networked manufacturing systems and (3) end-to-end digital integration of engineering across the entire value chain.

The horizontal integration through value networks refers to the integration of several IT systems, processes, resources and information flows within an organization and between other organizations, while the vertical integration and networked manufacturing systems concerns the integration of these elements through the departments and hierarchical levels of an organization, from Product Development to Manufacturing, Logistics and Sales. The aim of these two types of integration is to deliver an end-to-end solution across the entire value chain whose purpose is facilitating product customization and reducing operational costs through the use of CPS to digitally integrate the whole value chain [7].

According to Hermann et al. [18], Industry 4.0 concept can be understood as a collaborative term for technologies and concepts that embraces the whole organizations' value chain. This author, whose theory emphasizes the smart factory vision and the integration between its elements along the value chain through the use of key technology enablers, has identified four key aspects of Industry 4.0: (1) CPS, (2) IoT, (3) IoS, and (4) Smart Factory. In industry 4.0 framework, smart factories are organized by a modular structure, whose processes are controlled and monitored by CPS, that make decentralized decisions. On the other hand, IoT technology enables the cooperation between every CPS in the smart factory and operators in real-time, while IoS technology provides internal and cross organizational services over the whole value chain [18].

On the other hand, Weyer et al. [6] states that this new industrial paradigm embraces the development of intelligent environments that are able to bring the real and virtual world together through the use of CPS, integrating devices, machines, production modules and products, triggering actions and controlling each other autonomously. However, this author categorizes the central aspects of Industry 4.0 into three main paradigms [6]: (1) Smart Product, (2) Smart Machine and (3) Augmented Operator. This author introduces, besides the relevance of smart product and smart machine/factory, a new important aspect for Industry 4.0: the human machine interface and the emergence of new kinds of jobs.

The first paradigm regards the emergence of new market requirements and the development of smart products. These products are able to store large amount of data and interact with their environment, being self-aware and communicating autonomously with industrial systems [2]. Furthermore, they are able to provide information about their status during their whole lifecycle. Smart products, as CPS can be managed in real-time through the whole value chain, requesting the required resources for their completion [7].

The second paradigm, which is highly related with smart factory, regards the fact that, in the Industry 4.0 environment, machines are becoming CPS, which implies self-organized production systems with interconnected components, devices, production modules and products. The smart factory will be more intelligent, flexible and dynamic and smart machines will be able to improve production processes through self-optimization and autonomous decision-making process [19].

Lastly, Augmented Operator paradigm is related to the worker's technological support that is required in the manufacturing environment, which represents a challenge, since the operators will face a large variety of new tasks. Industry 4.0 introduces new types of interactions between operator and machines, as well as the coexistence between human and robots, which will completely change the current industrial workforce in order to answer the changing requirements and the increasing production variability [20].

Posada et al. [21] goes further, summing up and outlining the key aspects addressed by Industry 4.0: (1) the products mass customization enabled by the use of IT, (2) the automatic and flexible adaptation of production systems for changing requirements, (3) the tracking and self-awareness of parts and products and their capability to communicate within their environment, (4) the improved human machine interface, the coexistence with robots and the emergence of new ways of interaction and operation, (5) the communication within the smart factory and the production optimization enabled by Internet of Things and (6) the emergence of new services and business models, influencing the whole value chain [21]. In short, Industry 4.0 holds a huge potential, having impact in the entire value chain, through the optimization of production processes, enhancing the quality of products, strengthen the relationship between all stakeholders and offering new business models and new ways of operating [22].

4. Key Technologies Enablers for Industry 4.0

Industry 4.0 is a complex technological system that is being shaped fundamentally by connectivity, integration and production digitization, emphasizing the opportunities of integrating all elements in a value-adding system [23]. This concept embraces digital manufacturing technology, network communication technology, computer technology and automation technology [1]. Technology advancements regarding Industry 4.0 are eliminating the boundaries between the digital and physical world, integrating human and machine agents, materials, products, production systems and processes [10]. Industry 4.0 is allowing fast technological advancements in many areas, however, the emerging fourth industrial revolution is being predominantly shaped by the technical integration of Cyber-Physical Systems into manufacturing processes and the use of the Internet of Things and Services in industrial processes [7]. Consequently, this section provides a brief description about each key technology drivers for Industry 4.0, which mainly refer to CPS, IoT and IoS, as abovementioned.

4.1. *Cyber-Physical Systems*

Cyber-Physical Systems (CPS), which are frequently used to define Industry 4.0, represent one of the most significant advances regarding computer science and information technologies development. These systems consist in the interaction between the physical and the virtual environment, integrating, controlling and coordinating processes and operations and, simultaneously, providing and using data accessing and processing [24]. Generally, CPS can be defined as innovative technologies that enable the management of interconnected systems through the integration of their physical and computational environments [25].

The adoption of the Industry 4.0 paradigm in manufacturing environments requires further development and industrial implementation of CPS. The integration of these systems with production, logistics and services will led to an industrial transformation and CPS, which are specifically Cyber-Physical Production Systems (CPPS) when applied to production, will play an important role, since these systems consist in the connection across all levels of production between autonomous and cooperative elements (e.g. Smart Machines) and sub-systems (e.g. Smart Factories) [26]. To sum up, a CPS can be fundamentally described as an embedded system that exchanges data in an intelligent network that enables smart production. When the CPS is connected to the Internet, it is frequently known as “Internet of Things” [14]. The integration of CPS with manufacturing environment will allow the vertical and horizontal integration of IT systems and the interconnection between the whole supply chain, potentially transforming today’s factories into Industry 4.0 factories [25].

4.2. *Internet of Things and Internet of Services*

The Internet of Things (IoT) is an emerging term that combines different technologies and approaches, based on the connection between physical things and the Internet. Since the birth of the Internet, the interconnection between computers has become a reality and the technological development over the last decades made it possible to expand the Internet into a next level: smart objects [27]. Therefore, the smart object is the basis of a IoT vision, since this new paradigm consist in endowing everyday objects with intelligence, allowing them not only to collect information and interact with their environment, but also to be interconnected with other objects, exchanging data and triggering actions through the Internet [28].

The growing interest about this topic that is frequently pointed out as one of the main drivers of Industry 4.0 has resulted in the emergence of different visions and definitions. Generally, IoT can be defined as the Internet connection between everyday physical objects in the shop floor, people, systems and IT systems, creating a smart manufacturing environment often referred as smart factory [29]. Haller et al. [30] has defined IoT as “a world where physical objects are seamlessly integrated into the information network, and where the physical objects can become active participants in business processes. Services are available to interact with these smart objects over the Internet, query their state and any information associated with them, taking into account security and privacy issues” [30].

The Internet of Services (IoS) concept have emerged recently and will bring new opportunities to service industry, since it provides business and technical basis for business networks creation between service providers and customers. This concept pursuit a similar approach of IoT, but it is applied to services instead of physical entities. IoS can be

described as a new business model that will change profoundly the way services are provided, allowing a higher value creation that results from the relationship between every stakeholder within the value chain, such as the organization, customers, intermediaries, aggregators and suppliers [2], [31].

In industrial environments and value chains, the proliferation of IoT will provide several opportunities for users, manufacturers and companies, having a great impact in several fields, such as, automation, industrial manufacturing, logistics, business processes, process management and transportation [32], [33]. The term Industrial Internet of Things (IIoT) has been introduced to describe the application of IoT in industry, which implies the use of disruptive technology such as sensors, actuators, control systems, machine-to-machine, data analytics, and security mechanisms to improve modern industrial systems [34].

The IoT is opening new frontiers and many applications are emerging within three main pillars: (1) process optimization, (2) optimized resource consumption and (3) creation of complex autonomous systems [35]. The further development and proliferation of IoT techniques will allow things to become smarter, more reliable and more autonomous, enabling the provision of added-value products and services [36].

5. Impacts of Industry 4.0

Innovation and technological developments play an important role in every organization. However, the digital transformation advancements and the rising interconnectivity will bring new challenges to organizations, since Industry 4.0 will significantly change the products and manufacturing systems regarding design, processes, operations and services. Moreover, it is expected that Industry 4.0 can have further consequences on management and future jobs, allowing the creation of new business models, which will have a large effect on industry and markets, effectively affecting the whole product lifecycle, providing a new way of producing and doing business, allowing the improvement of processes and increasing the company's competitiveness.

Industry 4.0 will lead to potential deep changes in several domains that go beyond the industrial sector. Its impacts and influence can be categorized into six main areas: (1) Industry, (2) Products and services, (3) Business models and market, (4) Economy, (5) Work environment and (6) Skills development.

Industry is the sector that will most suffer the impacts of Industry 4.0. This new industrial paradigm will bring a new manufacturing vision that is characterized by decentralized and digitalized production, where the production elements are able to autonomously control themselves, trigger actions and respond to changes in their environment [10]. Moreover, the emerging paradigm proposes to fully integrate products and processes, shifting the production vision from mass production to mass customization, which brings a higher level of complexity [37]. Therefore, the production processes and operations will be deeply affected by the technological developments and the establishment of smart factories, allowing a greater flexibility in operations and a more efficient resource allocation. Industry 4.0 will have an important influence on industrial processes, manufacturing systems and supply chains. This new paradigm is transforming the current industrial landscape through three main points: (1) digitization of production, (2) automation and (3) linking the manufacturing site in a comprehensive supply chain. In that way, Industry 4.0 consists in full network integration and real-time information exchange [19]. The core of every industrial revolution is the productivity increase. However, the fourth industrial revolution goes further and, besides increasing productivity, will affect the whole supply chain from product development and engineering processes to outbound logistics.

Products and services are being highly influenced by this new industrial paradigm. In the last years, fast changes in economic landscape and dynamic market requirements have resulted in an increased demand for the development of more complex and smarter products [38]. The products will become more modular and configurable, promoting mass customization in order to meet specific customer requirements [14]. Hence, Industry 4.0 is characterized by innovation and introduction of new products and services as embedded systems that can become responsive and interactive, being able to be managed and track their activity in real-time, optimizing the whole value chain and providing relevant information about their status during their lifecycle [7].

Business models and market have rapidly changed in the last few years and new innovative business models will arise. The emergence of new disruptive technologies in Industry 4.0 context have changed the way products and services are sold and provided, affecting traditional businesses and bringing new business opportunities and models [15]. Therefore, value chains are becoming more responsive, since Industry 4.0 promotes the integration between

manufacturers and customers, allowing a closer interaction with customers and the adaptation of business models to market requirements [39]. The systems integration and complexity alongside the increasing digitization of industrial production will lead to the creation of more complex and digital market models [40], increasing competitiveness through the elimination of barriers between information and physical structures.

Economy can be influenced by the advent of the new paradigm and the emerging technological developments. The digitization consists in convergence between physical and virtual worlds and will have a widespread impact in every economic sector [9]. This will be the main driver for innovation, which will play a critical role in productivity and competitiveness.

Work environment is quickly changing due to technological advancements and Industry 4.0 is transforming jobs and required skills. The most significant change regards human-machine interface, which embraces the interaction between workers and a set of new ways of collaborative work [7]. The number of robots and smart machines is increasing and the physical and virtual worlds are merging, which means that a significant transformation is being launched in the current work environment. The increasing relevance of human-machine interfaces will promote the interaction between both production elements and the required communication between smart machines, smart products and employees, enhanced by the vision of IoT and IoS that is enabled by CPS. For that reason, ergonomic issues should be taken into account in the context of industry 4.0 and future systems should have a focus on workers and their importance [37], [41]. The integration of Industry 4.0 in manufacturing systems and the increasing implementation of new technologies will have an impact on job profiles, as well as on work management, organization and planning. The main challenge in this context is to avoid what is known as technological unemployment, redefining current jobs and taking measures to adapt the workforce for the new jobs that will be created [19].

Skills development, which will lead to demographic and social changes, is one of the most important key factor for a successful adoption and implementation of Industry 4.0 framework. The future work vision will demand for new competencies and it is necessary to create opportunities for the acquisition of the required skills through high quality training [10]. This new industrial paradigm will have a massive impact on labor market and professional roles, being crucial to ensure that more jobs are created than those that will disappear. The new required competency fields need to be included in education, since interdisciplinary thinking will play an important role and excellent skills in social and technical domains will be sought for [42]. Industry 4.0 will lead to an increased automation of tasks, which means that workers should be prepared for performing new tasks. The same applies for engineering education that holds a large of potential to train the professionals of the future and aware them about new technological trends and opportunities, as well as the managers that should adopt their management strategy to the new market requirements [10]. Moreover, increasingly more qualified staff will be required in technological fields to address Industry 4.0 requirements.

Briefly, Industry 4.0 represents an enormous potential in many areas and its implementation will have impacts in the entire value chain, improving production and engineering processes, enhancing the quality of products and services, optimizing the relationship between customers and organizations, bringing new business opportunities and economic benefits, changing the education requirements and transforming the current work environment.

6. Conclusions

The increased attention received by this new industrial paradigm commonly known as Industry 4.0 has raised many questions about this concept and its meanings, as well as the technological developments to be accomplished and the impacts that are related to the effective adoption of these advancements. This paper focuses on Industry 4.0 and contributes to the clarification of this concept that is characterized by connectivity and production digitization. Attention is paid to impacts on production systems, but also on management, economics and society at large. The transformation is being characterized by disruptive technological advancements that are eliminating the boundaries between the virtual and physical world, integrating workers, smart machines, smart products, machines, production systems and processes. However, Industry 4.0 is being predominantly shaped by two main drivers: Cyber-Physical Systems and the Internet of Things and Services.

In order to achieve better process efficiency and competitiveness, companies that are moving towards Industry 4.0 need to be aware of every aspect that can be influenced and what the main implications are, but also what the opportunities for innovation are. This new paradigm holds an enormous potential for organizations and, besides

industry transformation, it will have impact in many other fields, such as, products and services, new business models and market, economy, work environment and skills development.

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